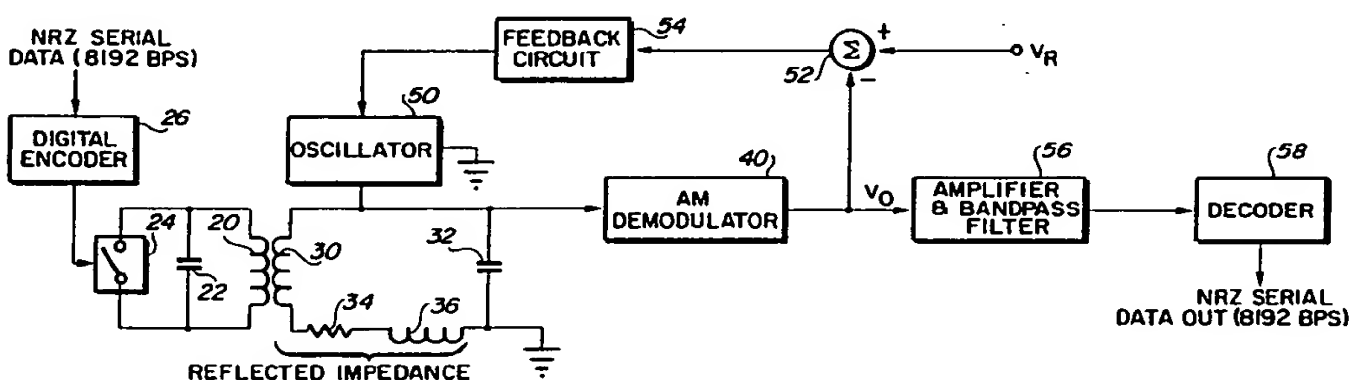




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(54) Title: HIGH SPEED REFLECTED IMPEDANCE TELEMETRY SYSTEM FOR IMPLANTABLE DEVICE



(57) Abstract

A telemetry system which will transmit data at a relatively high rate while retaining a high degree of accuracy is disclosed which utilizes a servo feedback loop (60) in conjunction with a conventional reflected impedance (34, 36) receiving front end parallel LC circuit (30, 32), an AM demodulator (40), and an oscillator (50) to drive the LC circuit (30, 32) at a desired frequency. The feedback loop (60) operates to keep the voltage across the LC circuit (30, 32) constant over time, and does not affect short term variations in the voltage across the LC circuit (30, 32) which are caused by the variations in the reflected impedance (34, 36). While frequency response of the system without the loop declines from a maximum value at zero frequency, the frequency response of the system of the present invention with the loop is shifted which permits data transmission at a substantially higher rate.

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HIGH SPEED REFLECTED IMPEDANCE TELEMETRY SYSTEM
FOR IMPLANTABLE DEVICE

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Background of the Invention

Field of the Invention - The present invention relates generally to a telemetry system for use in medical devices of various types and for various purposes implantable within the human body, and more particularly to a telemetry system which will transmit data at a relatively high rate while retaining a high degree of accuracy.

With the ever-shrinking size of electronic circuitry, the implantation into the human body of electronic medical devices has become more and more common. Although the most commonly known of such devices is the cardiac pacemaker, there are a variety of devices which are implanted into the human body, including devices for the stimulation or sensing, or both, of the brain, nerves, the spinal cord, muscles, bones, glands, or other body organs or tissues.

It will be appreciated by those skilled in the art that such implantable devices are becoming increasingly complex, and that more functions can be crammed into a relatively smaller electronic chip or circuit. Implantable medical devices have used bidirectional telemetry for a number of years. Information transmitted between the implanted device and an external transceiver may include, for example, device identification information, biological data, current operational parameters of the device, technical information regarding proper operation of the device, battery charge condition, revised operational parameters (programming information) for the device, and verification of information

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transmitted between the implanted device and the external transceiver.

5 With an ever-increasing amount of data being processed and available within the implantable device, there has been an corresponding increase in the need to transmit more data from the implanted device to the external transceiver for analysis, reprogramming of the implantable device, or other purposes. The need for more data to be transmitted in both directions has.
10 increased tremendously the amount of time required both to interrogate the implanted device and to reprogram the implanted device. An upper limit on the amount of data flowing between the implanted device and the external transceiver has therefore become
15 directly proportional to the amount of time which may reasonably be taken to interrogate and reprogram the implanted device.

Accordingly, it is desirable to achieve a higher rate of data transfer between the implanted device and the external transceiver to eliminate this artificial
20 impediment and to maximize the communication between the implanted device and the external transceiver. Of course, an increase in the rate of data exchange may not be obtained at the expense of accuracy in a medical device, particularly if the device is a life-sustaining device such as a pacemaker. Absolute
25 accuracy is required, and it is apparent that an increase in the rate of data transfer will be nullified by an increase in the amount of time spent to verify data to ensure the degree of accuracy
30 required.

The recent development of LSI circuits incorporating low current analog-to-digital converters has made the use of such converters in implantable
35 devices possible. There are, of course, limitations surrounding the design of new implantable systems or

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portions thereof, the most limiting of which is the consumption of energy by the system. Implanted systems are customarily powered by a long-lasting non-replaceable internal battery, and the current
5 consumption of a telemetry sub-system thus becomes perhaps the most important design factor to be considered.

Previously known devices have established various methods of communicating non-invasively through the
10 skin. For example, U.S. Patent No. 4,223,679, to Schulman et al., which patent is assigned to the assignee of the present invention, shows an implanted device which uses little or no current to transmit information by relying on reflected impedance of an
15 internal L-C circuit. Internal modulation circuits in the implanted device transmit digital or analog data by modulating the reflected impedance, and the external transceiver utilizes an oscillator having varying frequency and amplitude outputs determined by
20 a coupled RF magnetic field carrier to an L-C circuit in the external transceiver. This system works well, but, unfortunately, has speed limitations making it unsuitable for transmitting the amount of information contemplated herein.

25 Another type of device uses an active type transmitter, with the transmitted energy being taken from the implantable device battery. This type of device, which is illustrated in U.S. Patent No. 4,281,664, to Duggan, has a data rate which is limited
30 to approximately 100 BPS (bits per second). Another device which utilizes an active type transmitter is shown in U.S. Patent No. 4,453,162, to Daly et al. The Daly et al. device can not achieve more than 0.25 to 0.05 bps/carrier cycle, a rate too low for the
35 applications contemplated herein.

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5 Still another telemetry system is disclosed in my U.S. Patent No. 4,681,111, which increases the speed of the device disclosed in above-referenced U.S. Patent No. 4,223,679. U.S. Patent No 4,681,111 is hereby incorporated herein by reference. However, the maximum rate of this device is still limited by the bandwidth of the external device L-C oscillator. Those skilled in the art will also appreciate that it is not practical to increase the carrier frequency..

10 above approximately eight kHz, since the metal enclosure of the implanted device will experience eddy currents great enough to attenuate the signal significantly. In addition, increasing the carrier frequency makes electromagnetic interference from video display terminals, which are generally approximately 16 kHz, a significant problem. Consequently, techniques requiring a number of carrier cycles for each signal bit will be capable of achieving a speed of only two to four KBPS.

20 One possible solution is disclosed in my U.S. Patent Application No. 07/085,914, which application is hereby incorporated herein by reference. This system utilizes both in-phase and quadrature data components, and frequency modulates both data components into a single transmitted sinusoidal signal which varies in frequency between two selected frequencies. The signal is received and decoded, preferably by a coherent decoder, into in-phase and quadrature components, which are then integrated and

30 sampled to produce the two transmitted in-phase and quadrature data components, which may then be recombined to produce the transmitted data. The system requires only low power, and is capable of operating at a relatively high data rate while

35 retaining a high degree of accuracy due to the

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splitting of the signal into the in-phase and quadrature data components.

It will, however, be appreciated that there exists a substantial need for other telemetry systems which are capable of accurately transmitting and receiving data at a rate enabling the substantial amounts of data used by current implantable systems to be conveniently sent in a relatively short period of time. The amount of power required by the implanted portion of such a system must be minimal, so as not to adversely affect battery life. The system should be compact so as to not add significantly to the space required by the implanted device. Finally, it is also an objective that all of the aforesaid advantages and objectives be achieved without incurring any substantial relative disadvantage.

Summary of the Invention

The disadvantages and limitations of the background art discussed above are overcome by the present invention. With this invention, a servo loop is added to a conventional reflected impedance receiving front end circuit using an AM demodulator. Such a circuit typically has an external inductor in parallel with a capacitor to tune the inductor to an implanted inductor from which information is being transmitted. The AM demodulator is connected across the parallel LC combination. An oscillator is used to drive the LC circuit at a desired frequency.

The present invention adds a servo loop between the output of the AM demodulator and the oscillator. The feedback loop compares the voltage output from the AM demodulator with a reference voltage, and thus operates to keep the voltage across the LC circuit constant over time. The feedback loop does not affect short term variations in the voltage across the LC

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circuit which are caused by the variations in the reflected impedance since the data transmission frequency possible with the system of the present invention is relatively high.

5 The frequency response of the system of the present invention is thus tailored to the desired response required by a high speed telemetry channel. Mainly, the system frequency response (the response to the implanted device modulation), specified as center,
10 frequency and bandwidth, can be specified independently of the L-C oscillator parameters through use of the servo loop. While frequency response of the system without the loop declines from a maximum value at zero frequency, the frequency response of the
15 system of the present invention with the loop is shifted (to be centered around a center frequency) which in turn will permit transmission at a substantially higher data rate.

20 An amplifier and bandpass filter is driven by the output of the AM demodulator, with the output from the amplifier and bandpass filter driving a decoder. Alternately, an FM demodulator may be used in addition to the AM demodulator to demodulate the signal before it is supplied to the amplifier and bandpass filter
25 and the decoder. The AM demodulator, however, remains in the circuit and is still used as an integral part of the servo loop.

30 Thus, the system of the present invention is capable of accurately transmitting and receiving data at a high rate. The amount of power required by the implanted portion of such a system is based on the energy provided by the external device and the implanted device has to provide only minimal power, and as such the system of the present invention does
35 not adversely affect battery life. The system is compact so as to not add significantly to the space

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required by the implanted device. Finally, all of the aforesaid advantages and objectives are achieved without incurring any substantial relative disadvantage.

5

Description of the Drawings

These and other advantages of the present invention are best understood with reference to the drawings, in which:

10 Figure 1 is a functional schematic of a known reflected impedance telemetry system used with an AM demodulator in the receiving end;

Figure 2 illustrates the baseband equivalent to the circuit shown in Figure 1;

15 Figure 3 shows the frequency response limitations of the system shown in Figure 1;

Figure 4 is a functional schematic of a high speed reflected impedance telemetry system constructed according to the teachings of the present invention;

20 Figure 5 illustrates the high speed front end of the receiver of the telemetry system shown in Figure 4, with an AM demodulator being used in conjunction with a closed servo loop feedback circuit driving the oscillator;

25 Figure 6 illustrates the bandpass equivalent to the circuit shown in Figure 5.

Figure 7 illustrates the baseband equivalent to the circuit shown in Figure 6;

30 Figure 8 shows the system frequency response of the circuit shown in Figure 5;

Figure 9 shows selected signals in the transmitter and receiver; and

35 Figure 10 is a functional schematic of a high speed reflected impedance telemetry system similar to that shown in Figure 4, but with an FM demodulator being used in addition.

Detailed Description of the Preferred Embodiment

Before discussing the preferred embodiment of the present invention, it is useful to examine a known reflected impedance telemetry system to determine its shortcomings. Such a system is illustrated in Figure 1, which shows both the implanted and the external portions of such a system. An inductor or coil 20 is tuned to a resonant frequency f_0 by a capacitor 22 which is connected in parallel across the inductor 20. Also connected in parallel across the inductor 20 and the capacitor 22 is a low impedance semiconductor switch 24, which is typically a CMOS device.

The external receiver used to receive data transmitted from the implanted device has a coil or inductor 30 which is applied to the surface of the skin over the location of the inductor 20 of the implanted device. The two inductors 20 and 30 are constructed in a manner whereby they will magnetically couple to each other. As such, they may be regarded as two coils of a transformer having a low coupling coefficient. A capacitor 32 is connected across the inductor 30.

With the switch 24 open, the circuit will oscillate at the frequency f_0 in an essentially sinusoidal manner, with a sinusoidal voltage V_L across the inductor 20 and the capacitor 22. In this state, the circuit will dissipate energy taken from the external tank circuit including the inductor 30 and the capacitor 32. When the switch 24 is closed, the inductor 20 and the capacitor 22 are shorted. In this state, the circuit will dissipate lower energy taken from the external tank circuit including the inductor 30 and the capacitor 32. Accordingly, by opening and closing the switch 24, the voltage on the capacitor 32 is AM and FM modulated.

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Non-return-to-zero (NRZ) serial binary data is supplied by the implanted device to a digital encoder 26, which is used to open and close the switch 24 to modulate the voltage signal across the inductor 20. In the example used herein, an NRZ data bit of "0" is encoded by the digital encoder 26 to be two excursions from zero to one or from one to zero, while an NRZ data bit of "1" is encoded by the digital encoder 26 to be a single excursion from zero to one or from one to zero (see Figure 9).

A reflected impedance from the implanted circuit appears in series with the inductor 30 and the capacitor 32. The reflected impedance is illustrated in Figure 1 by a resistor 34 and an inductor 36 connected in series together with the inductor 30 and the capacitor 32. When the switch 24 is open, the resistance of the resistor 34 is high, and when the switch 24 is closed, the resistance of the resistor 34 is very low, near zero. When the switch 24 is opened, the inductance of the inductor 36 will have a low negative value, and while the switch 24 is closed the inductor 36 will have approximately zero inductance.

An oscillator 38 is connected to the tuned external circuit, and oscillates approximately at f_0 . As such, the inductor 30 and the capacitor 32 will oscillate at a frequency which is approximately f_0 . Generally, the inductor 30 and the capacitor 32 are tuned to f_0 to accomplish an efficient transfer of energy. The oscillator 38 may be a Colpitts circuit, or the circuit shown in Figure 2 in U.S. Patent No. 4,233,679, to Schulman.

As the switch 24 is opened and closed, the voltage across the capacitor 32 will change, as will the frequency of oscillation. When the switch 24 is opened, the voltage across the capacitor 32 will drop due to an increase in reflected resistance, and the

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frequency of oscillation will increase slightly. Therefore, it is apparent that as the switch 24 is opened and closed, the voltage across the capacitor 32 will be modulated. In addition, the main frequency of
5 oscillation of the circuit in the external device, which is f_0 , will be modulated somewhat by the switch 24 being opened and closed.

It will therefore be appreciated that the modulation imposed by the switch 24 on the implanted
10 tuned circuit will appear across the capacitor 32. Accordingly, a demodulator may be used to obtain the data being transmitted. In the circuit shown in Figure 1, an AM demodulator 40 is used. The AM demodulator 40 will extract the AM modulation produced
15 by the reflected impedance, with the output V_0 of the AM demodulator 40 containing the DC oscillator amplitude plus the AC modulation.

The AM demodulator 40 may typically be a diode 42 having its anode connected to the ungrounded side of
20 the capacitor 32, with its cathode being the output of the circuit at which V_0 appears. A resistor 44 and a capacitor 46 are connected together in parallel between the cathode of the diode 42 and ground. It will of course be recognized by those skilled in the
25 art that there are various other AM demodulator designs, and any of them could alternatively be used.

Typically an amplifier and band pass filter (not shown) may then be used to filter out the carrier frequency, thus extracting, amplifying and band
30 limiting the AC signal. Thus, only the frequency portion of the signal necessary to reconstruct the transmitted data is passed on. A decoder (not shown), is then used to decode the signal to provide the original transmitted data.

35 The most important characteristic of the system shown in Figure 1 is its maximum data rate. Consider

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for the moment that the digital encoder 26 is removed from the circuit of Figure 2, and that the NRZ serial data is applied directly to the switch 24. The AM modulation used is typically a double sideband type, since both sidebands are transmitted, and the frequency spectrum of the NRZ serial data itself is infinite. For a binary communication to be placed, the system bandwidth must be larger than the minimum Nyquist rate of $\frac{1}{2T} = 0.5f_r$, where

5 T is the bit duration and f_r is the bit rate.

10 From practical considerations, generally the bandwidth is not smaller than $0.75f_r$. A double sideband AM modulation will thus require at least a $1.5f_r$ bandwidth. The oscillator 38, the inductor 30,

15 and the capacitor 32 are equivalent to a 2-pole bandpass filter which passes the AM modulation on the f_0 carrier. Figure 2 illustrates the baseband equivalent to the circuit of Figure 1. In Figure 1, a resistor 57 has one side as the input to the circuit,

20 with the input being the reflected impedance. The other side of the resistor 57 is the output of the circuit on which V_0 appears. Connected across the output of the circuit and ground is a capacitor 59.

Figure 3 shows the frequency response of the system shown in Figure 1 (which response is indicated by the reference numeral 61). At baseband (after AM demodulation), and assuming the AM demodulator to be perfect with no modulation frequency alteration, the system is equivalent to a one-pole lowpass filter having a bandwidth f_{LC} . The width of this bandwidth f_{LC} is limited by the coil quality of factor Q as defined by the formula

25 Figure 3 shows the frequency response of the system shown in Figure 1 (which response is indicated by the reference numeral 61). At baseband (after AM demodulation), and assuming the AM demodulator to be perfect with no modulation frequency alteration, the system is equivalent to a one-pole lowpass filter having a bandwidth f_{LC} . The width of this bandwidth f_{LC} is limited by the coil quality of factor Q as defined by the formula

30 Figure 3 shows the frequency response of the system shown in Figure 1 (which response is indicated by the reference numeral 61). At baseband (after AM demodulation), and assuming the AM demodulator to be perfect with no modulation frequency alteration, the system is equivalent to a one-pole lowpass filter having a bandwidth f_{LC} . The width of this bandwidth f_{LC} is limited by the coil quality of factor Q as defined by the formula

$$(1) \quad f_{LC} = \frac{1}{2} \frac{f_0}{Q} = \frac{1}{2\pi R_0 C_0}.$$

35 In practice, the maximum rate at which transmitted data may be accurately received will be f_{LC} , since at

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frequencies above f_{LC} the amplitude of the signal will have dropped more than 3 dB. Accordingly, the maximum rate of transmission of data will be f_{LC} , which for the system shown in Figure 1 is only approximately 400
5 Hz. This effectively limits the rate of data transmission to a relatively low rate.

Referring now to Figure 4, a system illustrating the preferred embodiment of the present invention is shown. The implanted portion of the system is
10 identical to the system of Figure 1, and there are other similarities in the external portion of the system. The system of Figure 4 uses the inductor 30 which is applied to the surface of the skin over the location of the inductor 20 of the implanted device to
15 couple the two inductors 20 and 30 magnetically to each other. The capacitor 32 is connected across the inductor 30, with the reflected impedance from the implanted circuit being the resistor 34 and the inductor 36.

The system of Figure 4 also uses an oscillator 50 which is connected to the tuned external circuit, and which will oscillate approximately at f_0 . The inductor 30 and the capacitor 32 are again tuned to f_0 to accomplish an efficient transfer of energy. Again,
20 as the switch 24 is opened and closed, the voltage and frequency across the capacitor 32 will be modulated.

Accordingly, a demodulator may be used to obtain the data being transmitted, and the AM demodulator 40 is again used. The AM demodulator 40 will extract the
30 AM modulation produced by the reflected impedance, with the output V_o of the AM demodulator 40 containing the DC oscillator amplitude plus the AC modulation. The circuit of Figure 4 differs from the circuit of Figure 1 in that a feedback loop is used between the
35 output V_o of the AM demodulator 40 and the oscillator 50 which is used to drive the external circuit.

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A comparator 52 is used to compare the AM demodulator 40 output V_O with a reference voltage V_R . The output of the comparator 52 is supplied to a feedback circuit 54, the output of which is used to drive the oscillator 50. The feedback loop will thus operate to keep the voltage across the capacitor 32 constant over time. It must be noted at this point that the feedback loop will not affect short term variations in the voltage across the capacitor 32 which are caused by the variations in the reflected impedance caused by the switch 24 being opened and closed. This is so since the frequency at which the switch 24 is opened and closed is relatively high, as will become evident below.

Also connected to the output of the AM demodulator 40 is an amplifier and bandpass filter 56, which is used to amplify and filter the signal from the AM demodulator 40. Finally, a decoder 58 is used to decode the amplified and filtered signal to obtain the original data. The amplifier and bandpass filter 56 and the decoder 58 are of standard design and are well known in the art.

Referring next to Figure 5, a circuit 60 which will perform the functions of the comparator 52 and the feedback circuit 54 is shown. In this circuit 60, an operational amplifier 62 is shown which is connected as an integrator. The reference voltage V_R is connected to the positive input of the operational amplifier 62. A resistor 64 is connected between the output V_O of the AM demodulator 40 and the negative input of the operational amplifier 62. A capacitor 66 is connected on one side to the negative input of the operational amplifier 62, and on the other side to one side of a resistor 68. The other side of the resistor 68 is connected to the output of the operational amplifier 62.

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To complete the feedback loop, the output of the operational amplifier 62 is connected to the oscillator 50. The output from the operational amplifier 62 will keep the voltage output from the oscillator 50 constant over time, as mentioned above. This feedback loop has two essential effects. The first of these effects is that the amplitude of the output from the oscillator 50 will be such that the DC output from the AM detector 40 will be constant, equal to V_R .

The second effect of the feedback loop is that the transfer function from the reflected impedance modulation to the output V_O of the AM demodulator 40 will no longer be a 1-pole lowpass response, but rather a bandpass response. The bandpass equivalent of the circuit shown in Figure 5 is shown in Figure 6. The output from the operational amplifier 62 is connected to drive an amplifier 70. A coefficient K is equal to the derivative of V_O divided by the derivative of V_1 . The output of the amplifier 70 is supplied as an input to a summer 72, the other input of which is the external modulation V_i caused by the variations in the reflected impedance. The output of the summer 72 drives the oscillator 50.

Taking the lowpass baseband equivalent of the circuit shown in Figure 6, we obtain the circuit of Figure 7. The positive input of the operational amplifier 62 is grounded. Accordingly, the output of the summer 72 is supplied to the one side of the resistor 57, with the other side of the resistor 57 being the output V_O . The capacitor 59 is connected across the output V_O and ground. The resistor 57 and the capacitor 59 make up a four pole low pass filter equivalent to the one shown in Figure 2.

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By performing the following elementary control loop calculations, the determination of an overall input-output transfer function $H(s)$ may be made:

$$(2) \quad H(s) = \frac{V_o}{V_i}$$

$$(3) \quad \omega_{LC} = 2\pi f_{LC} = \frac{1}{R_o C_o}$$

$$(4) \quad H_{LC} = \frac{1}{1 + \frac{s}{\omega_{LC}}}$$

10

$$(5) \quad \frac{V_o}{V_i} = \frac{H_{LC}}{1 - H_{LC}H_f} = H(s)$$

$$(6) \quad H_f = -K \frac{1 + R_2 C_2 s}{R_1 C_2 s}$$

15

$$(7) \quad H(s) = \frac{\omega_{LC} s}{s^2 + \frac{R_1 + KR_2}{R_1} \omega_{LC} s + K \frac{\omega_{LC}}{R_1 C_2}}$$

$$(8) \quad \omega_{obp} = \sqrt{K \frac{\omega_{LC}}{R_1 C_2}}$$

20

$$(9) \quad Q = \frac{R_1}{R_1 + KR_2} \frac{\omega_{obp}}{\omega_{LC}}$$

25

By inspection, it may be seen that $H(s)$ is a standard 2-pole bandpass response having a center frequency ω_{obp} and a Quality factor Q which may be tailored to the application, and which are no longer solely determined by the oscillator L-C elements. Figure 8 illustrates how the new frequency response (indicated by the reference numerals 74 and 76) appears compared to the L-C response of the system of Figure 1 (indicated by the reference numeral 61, which response was also illustrated in Figure 3).

30

35

As may be seen from the $H(s)$ relation (equation 7) above and from Figure 8, the system response 74 of the system shown in Figure 4 at zero frequency is zero as opposed to maximum in the systems of Figure 1. The system response 74 instead is centered around the

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frequency ω_{obp} , and the useful bandwidth is substantially wider than the useful bandwidth of the system of Figure 1.

Referring for the moment to Figure 4, the digital encoder 26 has the task of changing the frequency spectrum from NRZ (non-return-to-zero), which has components down to DC, into a spectrum which contains no components close to zero frequency. In the preferred embodiment of the present invention, an MSK (minimum-shift-keying) encoder is used which has a first frequency f_1 which is 8192 Hz, and a second frequency f_2 which is 4096 Hz. In the preferred embodiment, there is a straight coding rule in which a zero will be transmitted as f_1 and a 1 will be transmitted as f_2 , as shown in Figure 9.

The voltage across the capacitor 32 is shown in Figure 9, with the associated output from the AM demodulator 40, which is one side of the voltage across the capacitor 32. The amplifier and bandpass filter 56 produces a signal responsive to the non-DC portion of the envelope of the output from the AM demodulator 40. The signal output of the amplifier and bandpass filter 56 will then be used by the decoder 58 to decode the signal back to NRZ.

Construction of the decoder 58 will be apparent to one skilled in the art. An MSK encoding is known to require a relatively low transmission bandwidth. In fact it can work on a two-sided bandwidth of 0.7 divided by the period T . This results in the factor 0.7 being multiplied by the frequency 8192 Hz to obtain a 5734 Hz bandwidth which is centered on f_{obp} of $(8192 + 4096)/2$, or 6144 Hz.

The choice of f_1 and f_2 can lead to simplification of the decoder 58. The best decoder performance will be obtained using a coherent decoder which, using a PLL (phase-locked-loop), regenerates at

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the receiver the two carriers f_1 and f_2 , as well as the bit clock timing. However, here the bit clock is equal to f_1 and $f_2 = 1/2f_1$, so the carriers may be obtained very simply. A non-coherent decoder could
5 also be used, with reduced performance but with simplified circuits. Detailed circuit schematics for the digital encoder 26, the amplifier and bandpass filter 56, and the decoder 58 are not presented since they may be implemented in a multitude of ways well
10 known to persons skilled in the art.

Referring next to Figure 10, it should be noted that while the AM demodulator 40 is necessarily contained in the loop, an FM demodulator 80 could also be connected with its input across the capacitor 32.
15 The output of the FM demodulator 80 would then drive the amplifier and bandpass filter 56.

It should also be noted that such telemetry systems typically have provisions to work in the opposite direction, that is from the external device
20 to the implanted device. In this case, a receiver detector would be connected across the inductor 20.

It may therefore be appreciated from the above detailed description of the preferred embodiment of the present invention that it is capable of accurately
25 transmitting and receiving data at a high rate. The amount of power required by the implanted portion of such a system is minimal, and as such does not adversely affect battery life. The system is compact so as to not add significantly to the space required
30 by the implanted device. Finally, all of the aforesaid advantages and objectives are achieved without incurring any substantial relative disadvantage.

Although an exemplary embodiment of the present
35 invention has been shown and described, it will be apparent to those having ordinary skill in the art

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that a number of changes, modifications, or alterations to the invention as described herein may be made, none of which depart from the spirit of the present invention. All such changes, modifications, and alterations should therefore be seen as within the scope of the present invention.

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CLAIMSWhat is claimed is:

1. A telemetry system for use with an implantable
5 device, comprising:

an inductor for receiving an information-
containing magnetic field;

a capacitor connected in parallel across said
inductor;

10 an oscillator connected to drive said inductor
and said capacitor;

an AM demodulator connected across said inductor
and said capacitor, said AM demodulator having an
output containing an AC component and a DC component;
15 and

feedback loop means connected between the output
of said AM demodulator and said oscillator, said
feedback loop means for maintaining the DC component
of the output of said AM demodulator constant.

20

2. A telemetry system as defined in Claim 1, wherein
said inductor and said capacitor have values to tune
them to a frequency f_0 , and said oscillator is set to
oscillate at a frequency which is approximately f_0 .

25

3. A telemetry system as defined in Claim 1, wherein
said oscillator is controlled by said feedback loop
means to maintain the signal driving said inductor and
said capacitor at a constant level.

30

4. A telemetry system as defined in Claim 1, said
inductor having a first terminal and a second
terminal, said capacitor having a first terminal and a
second terminal, said first terminal of said inductor
35 being connected to said first terminal of said
capacitor, said second terminal of said inductor being

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connected to said second terminal of said capacitor, said second terminals being grounded, wherein said AM demodulator comprises:

5 a diode having a cathode and an anode, said anode connected to said first terminals of said inductor and said capacitor;

10 a second capacitor having first and second terminals, said first terminal of said second capacitor being connected to said cathode of said diode, said second terminal of said second capacitor being connected to said second terminal of said inductor and said second terminal of said capacitor ;

15 a resistor having first and second terminals, said first terminal of said resistor being connected to said first terminal of said second capacitor and said cathode of said diode, said second terminal of said resistor being connected to said second terminal of said second capacitor, said second terminal of said inductor, and said second terminal of said capacitor.

20

5. A telemetry system as defined in Claim 1, wherein said feedback loop means is so arranged and configured to convert the response of said system from a 1-pole lowpass response to a bandpass response.

25

6. A telemetry system as defined in Claim 1, wherein said feedback loop means comprises:

30 an operational amplifier having a positive input, a negative input, and an output, said positive input of said operational amplifier being supplied with a DC reference voltage;

a first resistor connected between the output of said AM demodulator and said negative input of said operational amplifier;

35 a second capacitor having a first terminal and a second terminal, said first terminal of said second

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capacitor being connected to said negative input of said operational amplifier; and

5 a second resistor having a first terminal and a second terminal, said first terminal of said second resistor being connected to said second terminal of said second capacitor, said second terminal of said second resistor being connected to the output of said operational amplifier, the output of said operational amplifier also being connected to drive said
10 oscillator.

7. A telemetry system as defined in Claim 1, additionally comprising:

15 an amplifier and bandpass filter having as an input the output from said AM demodulator, said amplifier and bandpass filter providing an output; and
a decoder having as an input the output from said amplifier and bandpass filter.

20 8. A telemetry system as defined in Claim 1, additionally comprising:

an FM demodulator connected across said inductor and said capacitor, said FM demodulator having an output;

25 an amplifier and bandpass filter having as an input the output from said FM demodulator, said amplifier and bandpass filter providing an output; and
a decoder having as an input the output from said amplifier and bandpass filter.

30

9. A telemetry system for use with an implantable device, comprising:

a first inductor for transmitting an information-containing magnetic field;

35 a first capacitor connected in parallel across said first inductor;

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a switch connected in parallel across said first inductor and said first capacitor;

means for periodically, sequentially opening and closing said switch to modulate a voltage across said first inductor and said first capacitor;

a second inductor for receiving said information-containing magnetic field;

a second capacitor connected in parallel across said second inductor;

an oscillator connected to drive said second inductor and said second capacitor;

an AM demodulator connected across said second inductor and said second capacitor, said AM demodulator having an output containing an AC component and a DC component; and

feedback loop means connected between the output of said AM demodulator and said oscillator, said feedback loop means for maintaining the DC component of the output of said AM demodulator constant.

10. A telemetry system as defined in Claim 9, wherein said means for periodically, sequentially opening and closing said switch comprises:

a digital encoder, said switch being open when the output of said digital encoder is a digital "0" and closed when the output of said digital encoder is a digital "1."

11. A telemetry system as defined in Claim 10, wherein a data bit of "0" is encoded by said digital encoder to be two excursions from zero to one or from one to zero, while a data bit of "1" is encoded by said digital encoder to be a single excursion from zero to one or from one to zero.

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12. A telemetry system as defined in Claim 9, wherein said first inductor and said first capacitor have values to tune them to a frequency f_0 , and said oscillator is set to oscillate at a frequency which is approximately f_0 .

13. A telemetry system as defined in Claim 12, wherein said second inductor and said second capacitor have values to tune them to said frequency f_0 .

14. A telemetry system as defined in Claim 9, wherein said oscillator is controlled by said feedback loop means to maintain the signal driving said inductor and said capacitor at a constant level.

15. A telemetry system as defined in Claim 9, wherein said feedback loop means is so arranged and configured to convert the response of said system from a 1-pole lowpass response to a bandpass response.

16. A telemetry system as defined in Claim 9, wherein said feedback loop means comprises:

an operational amplifier having a positive input, a negative input, and an output, said positive input of said operational amplifier being supplied with a DC reference voltage;

a first resistor connected between the output of said AM demodulator and said negative input of said operational amplifier;

a second capacitor having a first terminal and a second terminal, said first terminal of said second capacitor being connected to said negative input of said operational amplifier; and

a second resistor having a first terminal and a second terminal, said first terminal of said second resistor being connected to said second terminal of

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5 said second capacitor, said second terminal of said second resistor being connected to the output of said operational amplifier, the output of said operational amplifier also being connected to drive said oscillator.

17. A telemetry system as defined in Claim 9, additionally comprising:

10 an amplifier and bandpass filter having as an input the output from said AM demodulator, said amplifier and bandpass filter providing an output; and
a decoder having as an input the output from said amplifier and bandpass filter.

15 18. A telemetry system as defined in Claim 9, additionally comprising:

an FM demodulator connected across said inductor and said capacitor, said FM demodulator having an output;
20 an amplifier and bandpass filter having as an input the output from said FM demodulator, said amplifier and bandpass filter providing an output; and
a decoder having as an input the output from said amplifier and bandpass filter.

25 19. A telemetry system for use with an implantable device, comprising:

an LC tank circuit having an inductor for receiving an information-containing magnetic field;

30 an oscillator connected to drive said LC tank circuit;

an AM demodulator connected across said inductor and said capacitor, said AM demodulator having an output containing an AC component and a DC component;
35 and

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means for maintaining the DC component of the output of said AM demodulator constant.

20. A method of telemetering data between an
5 implantable device and an external device, comprising:
transmitting an information-containing magnetic
field;
receiving an information-containing magnetic
field with an inductor;
10 connecting a capacitor in parallel across said
inductor;
driving said inductor and said capacitor with an
oscillator;
demodulating the signal across said inductor and
15 said capacitor with an AM demodulator, said AM
demodulator having an output containing an AC
component and a DC component; and
maintaining the DC component of the output of
said AM demodulator constant by connecting feedback
20 loop means between the output of said AM demodulator
and said oscillator.

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AMENDED CLAIMS

[received by the International Bureau on 18 September 1991 (18.09.91);
original claims 1,9,19 and 20 amended; other claims
unchanged (8 pages)]

1. A telemetry system for use with an implantable
5 device, comprising:
 an inductor for receiving an information-
 containing magnetic field;
 a capacitor connected in parallel across said
inductor;
10 an oscillator connected to drive said inductor
and said capacitor;
 said inductor and capacitor and oscillator
causing said telemetry system to assume a first
frequency response having a first bandwidth;
15 an AM demodulator connected across said inductor
and said capacitor, said AM demodulator having an
output containing an AC component and a DC component;
and
 feedback loop means connected between the output
20 of said AM demodulator and said oscillator, said
feedback loop means for maintaining the DC component
of the output of said AM demodulator constant and for
further changing the frequency response of said
telemetry system to assume a center frequency having a
25 second bandwidth greater than said first bandwidth,
thereby permitting a higher rate of change of said
information-containing magnetic field, and hence a
higher data rate transfer.
- 30 2. A telemetry system as defined in Claim 1, wherein
said inductor and said capacitor have values to tune
them to a frequency f_0 , and said oscillator is set to
oscillate at a frequency which is approximately f_0 .

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3. A telemetry system as defined in Claim 1, wherein said oscillator is controlled by said feedback loop means to maintain the signal driving said inductor and said capacitor at a constant level.

5

4. A telemetry system as defined in Claim 1, said inductor having a first terminal and a second terminal, said capacitor having a first terminal and a second terminal, said first terminal of said inductor being connected to said first terminal of said capacitor, said second terminal of said inductor being connected to said second terminal of said capacitor, said second terminals being grounded, wherein said AM demodulator comprises:

10

15 a diode having a cathode and an anode, said anode connected to said first terminals of said inductor and said capacitor;

a second capacitor having first and second terminals, said first terminal of said second capacitor being connected to said cathode of said diode, said second terminal of said second capacitor being connected to said second terminal of said inductor and said second terminal of said capacitor ;

20

a resistor having first and second terminals, said first terminal of said resistor being connected to said first terminal of said second capacitor and said cathode of said diode, said second terminal of said resistor being connected to said second terminal of said second capacitor, said second terminal of said inductor, and said second terminal of said capacitor.

25

30

5. A telemetry system as defined in Claim 1, wherein said feedback loop means is so arranged and configured to convert the response of said system from a 1-pole lowpass response to a bandpass response.

35

6. A telemetry system as defined in Claim 1, wherein said feedback loop means comprises:

an operational amplifier having a positive input, a negative input, and an output, said positive input
5 of said operational amplifier being supplied with a DC reference voltage;

a first resistor connected between the output of said AM demodulator and said negative input of said operational amplifier;

10 a second capacitor having a first terminal and a second terminal, said first terminal of said second capacitor being connected to said negative input of said operational amplifier; and

a second resistor having a first terminal and a second terminal, said first terminal of said second resistor being connected to said second terminal of said second capacitor, said second terminal of said second resistor being connected to the output of said operational amplifier, the output of said operational
15 amplifier also being connected to drive said oscillator.

7. A telemetry system as defined in Claim 1, additionally comprising:

25 an amplifier and bandpass filter having as an input the output from said AM demodulator, said amplifier and bandpass filter providing an output; and

a decoder having as an input the output from said amplifier and bandpass filter.

30

8. A telemetry system as defined in Claim 1, additionally comprising:

an FM demodulator connected across said inductor and said capacitor, said FM demodulator having an
35 output;

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an amplifier and bandpass filter having as an input the output from said FM demodulator, said amplifier and bandpass filter providing an output; and
a decoder having as an input the output from said
5 amplifier and bandpass filter.

9. A telemetry system for use with an implantable device, comprising:

10 a first inductor for transmitting an information-containing magnetic field;

a first capacitor connected in parallel across said first inductor;

a switch connected in parallel across said first inductor and said first capacitor;

15 means for periodically, sequentially opening and closing said switch to modulate a voltage across said first inductor and said first capacitor;

a second inductor for receiving said information-containing magnetic field;

20 a second capacitor connected in parallel across said second inductor;

an oscillator connected to drive said second inductor and said second capacitor;

25 said second inductor, second capacitor and oscillator causing said telemetry system to assume a first frequency response having a first bandwidth;

an AM demodulator connected across said second inductor and said second capacitor, said AM demodulator having an output containing an AC
30 component and a DC component; and

feedback loop means connected between the output of said AM demodulator and said oscillator, said feedback loop means for maintaining the DC component of the output of said AM demodulator constant and for
35 further changing the frequency response of said telemetry system to assume a center frequency having a

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second bandwidth greater than said first bandwidth, thereby permitting a higher rate of change of said information-containing magnetic field, and hence a higher data rate transfer.

5

10. A telemetry system as defined in Claim 9, wherein said means for periodically, sequentially opening and closing said switch comprises:

10 a digital encoder, said switch being open when the output of said digital encoder is a digital "0" and closed when the output of said digital encoder is a digital "1."

11. A telemetry system as defined in Claim 10, wherein a data bit of "0" is encoded by said digital encoder to be two excursions from zero to one or from one to zero, while a data bit of "1" is encoded by said digital encoder to be a single excursion from zero to one or from one to zero.

20

12. A telemetry system as defined in Claim 9, wherein said first inductor and said first capacitor have values to tune them to a frequency f_0 , and said oscillator is set to oscillate at a frequency which is approximately f_0 .

25

13. A telemetry system as defined in Claim 12, wherein said second inductor and said second capacitor have values to tune them to said frequency f_0 .

30

14. A telemetry system as defined in Claim 9, wherein said oscillator is controlled by said feedback loop means to maintain the signal driving said inductor and said capacitor at a constant level.

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15. A telemetry system as defined in Claim 9, wherein said feedback loop means is so arranged and configured to convert the response of said system from a 1-pole lowpass response to a bandpass response.

5

16. A telemetry system as defined in Claim 9, wherein said feedback loop means comprises:

an operational amplifier having a positive input, a negative input, and an output, said positive input of said operational amplifier being supplied with a DC reference voltage;

a first resistor connected between the output of said AM demodulator and said negative input of said operational amplifier;

a second capacitor having a first terminal and a second terminal, said first terminal of said second capacitor being connected to said negative input of said operational amplifier; and

a second resistor having a first terminal and a second terminal, said first terminal of said second resistor being connected to said second terminal of said second capacitor, said second terminal of said second resistor being connected to the output of said operational amplifier, the output of said operational amplifier also being connected to drive said oscillator.

17. A telemetry system as defined in Claim 9, additionally comprising:

an amplifier and bandpass filter having as an input the output from said AM demodulator, said amplifier and bandpass filter providing an output; and

a decoder having as an input the output from said amplifier and bandpass filter.

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18. A telemetry system as defined in Claim 9, additionally comprising:

5 an FM demodulator connected across said inductor and said capacitor, said FM demodulator having an output;

an amplifier and bandpass filter having as an input the output from said FM demodulator, said amplifier and bandpass filter providing an output; and

10 a decoder having as an input the output from said amplifier and bandpass filter.

19. A telemetry system for use with an implantable device, comprising:

15 an LC tank circuit having an inductor for receiving an information-containing magnetic field, and a capacitor connected across said inductor, said LC tank circuit causing said telemetry system to assume a first frequency response having a first bandwidth;

20 an oscillator connected to drive said LC tank circuit;

25 an AM demodulator connected across said inductor and said capacitor, said AM demodulator having an output containing an AC component and a DC component; and

30 means for maintaining the DC component of the output of said AM demodulator constant and for further changing the frequency response of said telemetry system to assume a center frequency having a second bandwidth greater than said first bandwidth, thereby permitting a higher rate of change of said information-containing magnetic field, and hence a higher data rate transfer.

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20. A method of telemetering data between an implantable device and an external device, comprising:
transmitting an information-containing magnetic field;

5 receiving an information-containing magnetic field with an inductor;

connecting a capacitor in parallel across said inductor;

10 driving said inductor and said capacitor with an oscillator;

demodulating the signal across said inductor and said capacitor with an AM demodulator, said AM demodulator having an output containing an AC component and a DC component; and

15 widening the bandwidth of a receiving circuit comprising said inductor, capacitor and oscillator by connecting feedback loop means between the output of said AM demodulator and said oscillator, whereby data may be telemetered between said implantable device and
20 said external device at a faster rate.

STATEMENT UNDER ARTICLE 19

Claim 1 has been amended to now include the following limitation:

..."said inductor and capacitor and oscillator causing said telemetry system to assume a first frequency response having a first bandwidth;" and

..."and for further changing the frequency response of said telemetry system to assume a center frequency having a second bandwidth greater than said first bandwidth, thereby permitting a higher rate of change of said information-containing magnetic field, and hence a higher data rate transfer".

Claim 9 has been amended to now include:

..."said second inductor, second capacitor and oscillator causing said telemetry system to assume a first frequency response having a first bandwidth;" and

..."and for further changing the frequency response of said telemetry system to assume a center frequency having a second bandwidth greater than said first bandwidth, thereby permitting a higher rate of change of said information-containing magnetic field, and hence a higher data rate transfer".

Claim 19 has been amended to now include:

...", and a capacitor connected across said inductor, said LC tank circuit causing said telemetry system to assume a first frequency response having a first bandwidth" and

..."and for further changing the frequency response of said telemetry system to assume a center frequency having a second bandwidth greater than said first bandwidth, thereby permitting a higher rate of change of said information-containing magnetic field, and hence a higher data rate transfer".

Claim 20 has been amended to now include:

..."widening the bandwidth of a receiving circuit comprising said inductor, capacitor and oscillator" and

...", whereby data may be telemetered between said implantable device and said external device at a faster rate".

Moreover, the words [maintaining the DC component of the output of said AM demodulator constant] have been deleted.

NRZ SERIAL DATA

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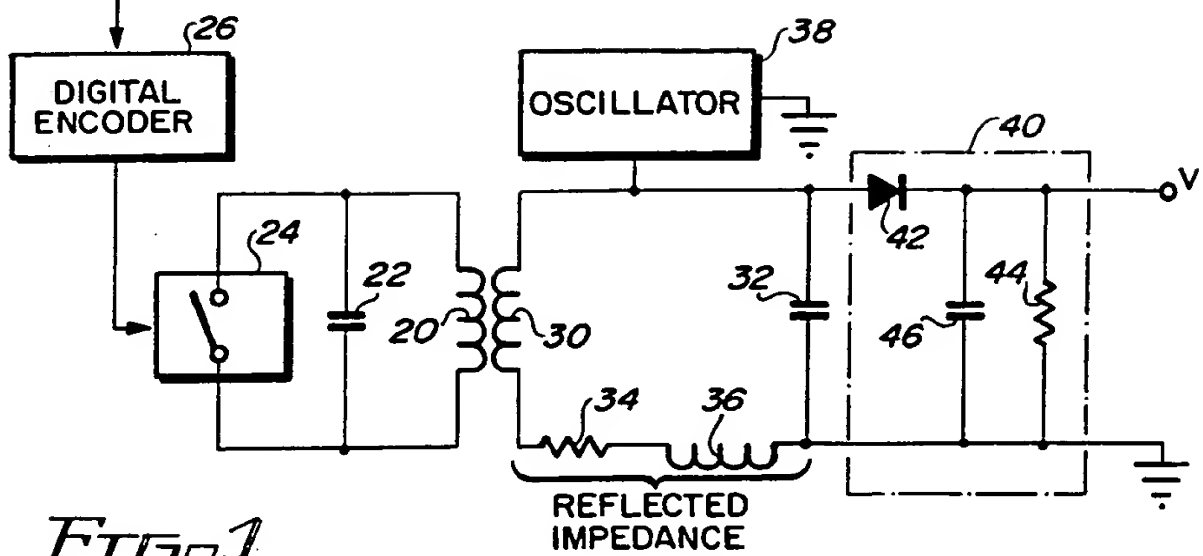


FIG. 1

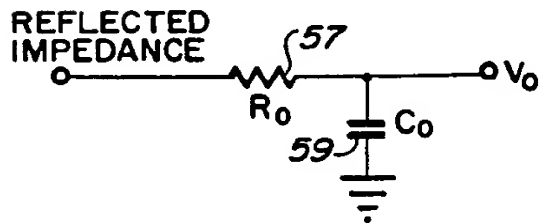


FIG. 2

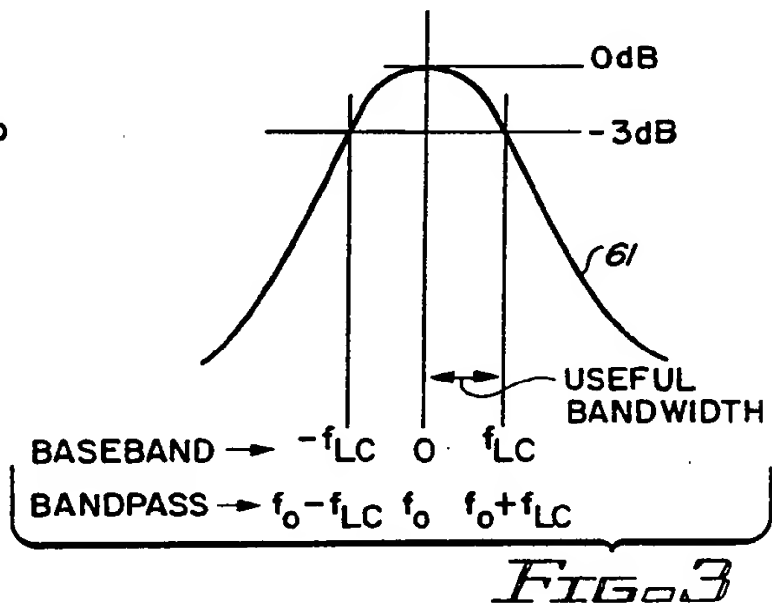


FIG. 3

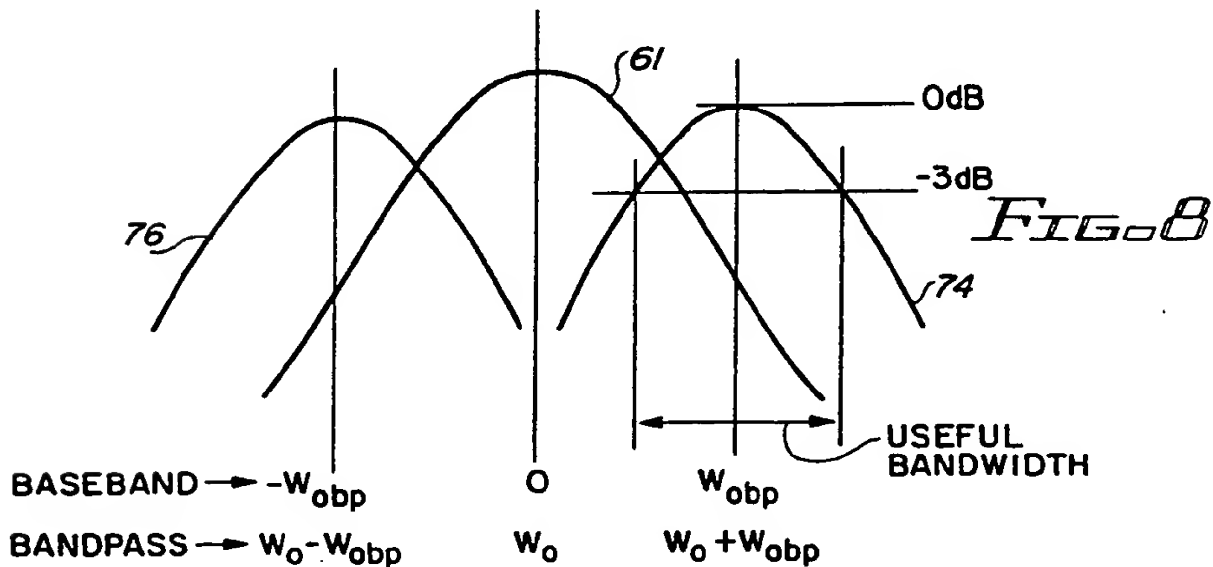
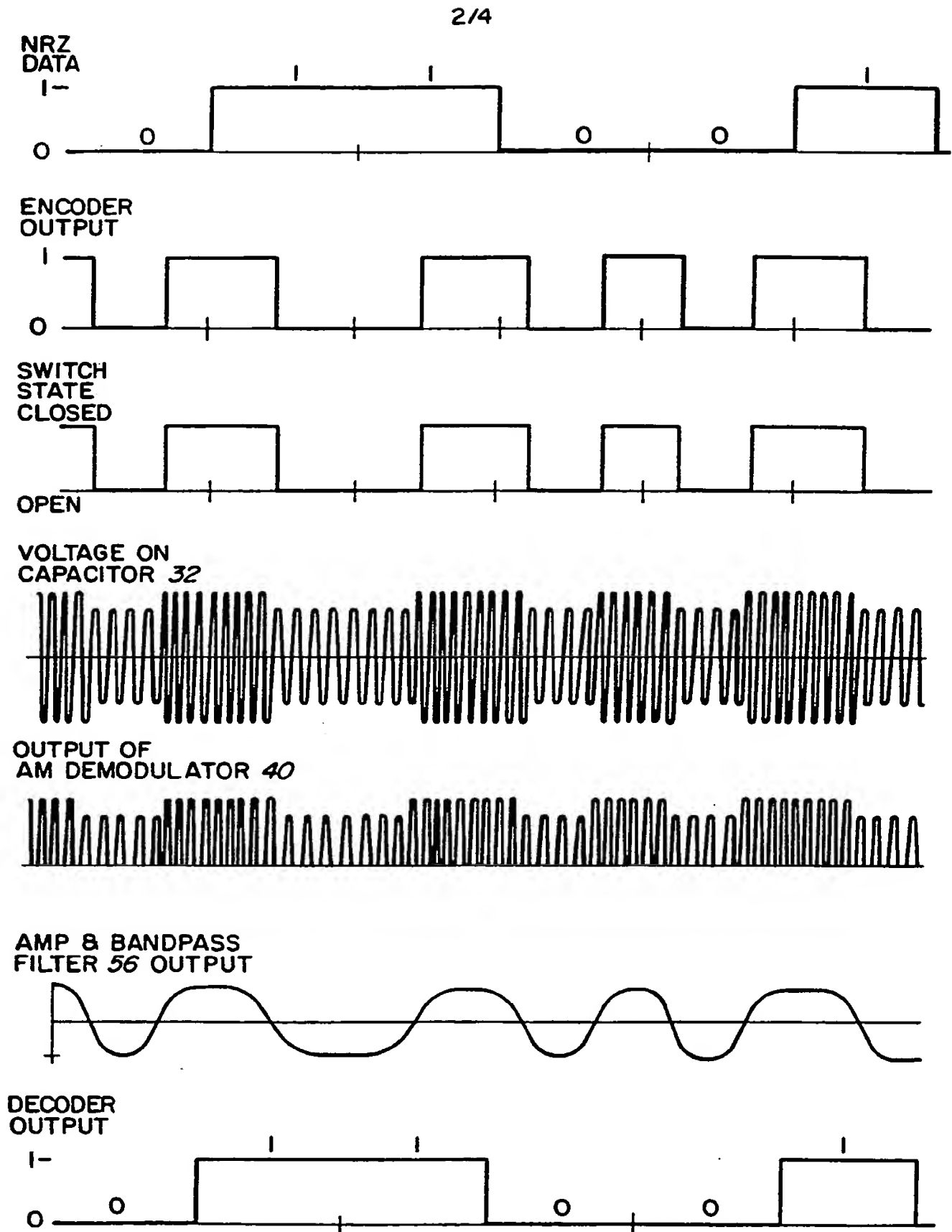


FIG. 8

*FIG. 9*

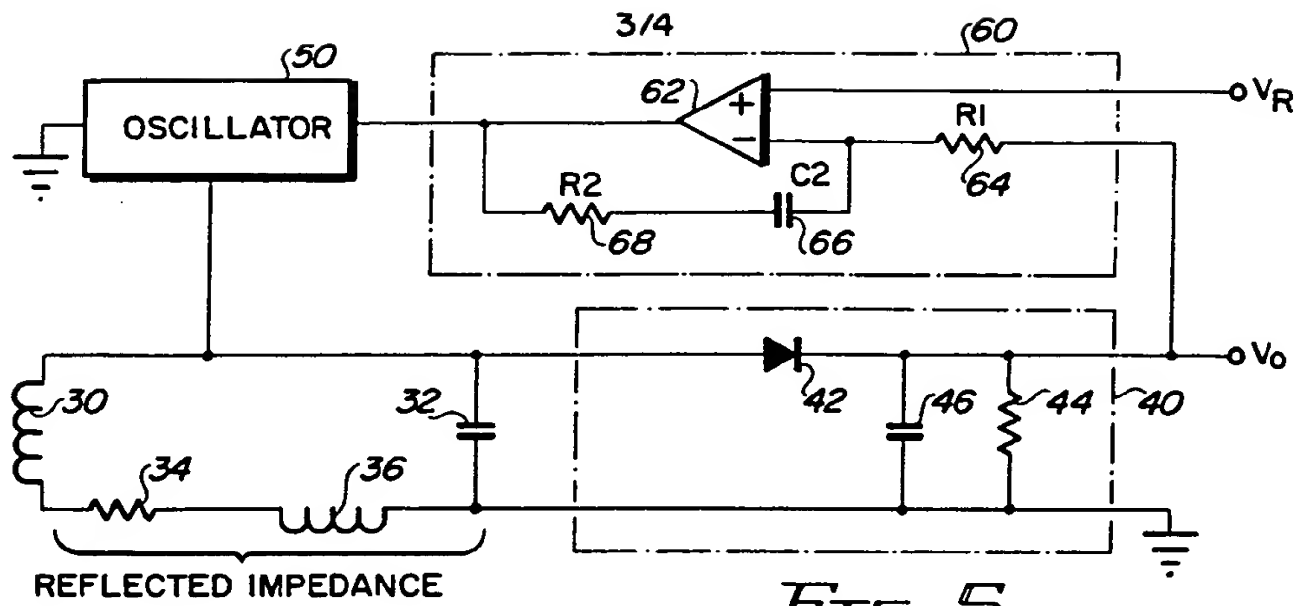


FIG. 5

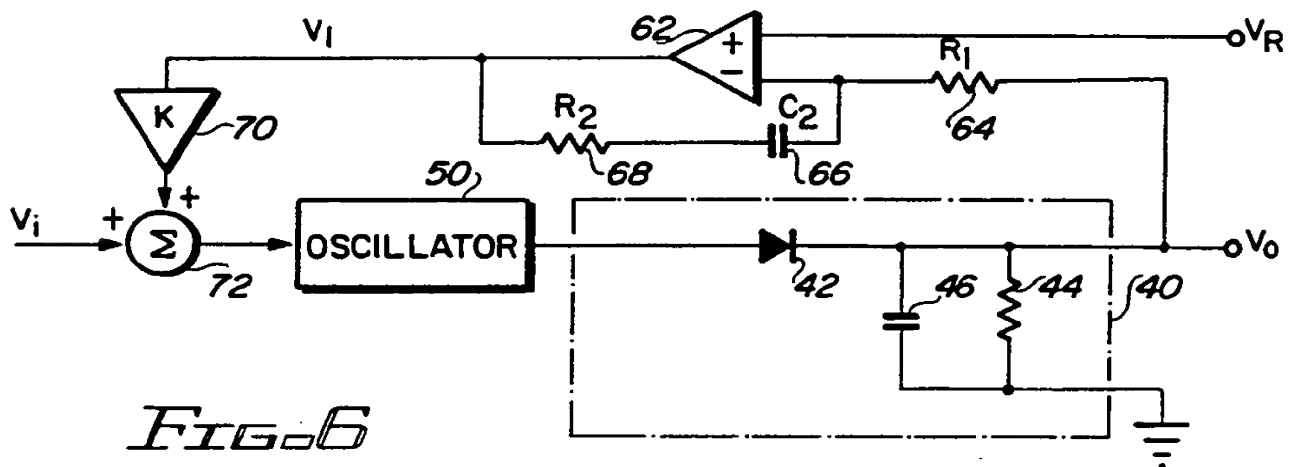


FIG. 6

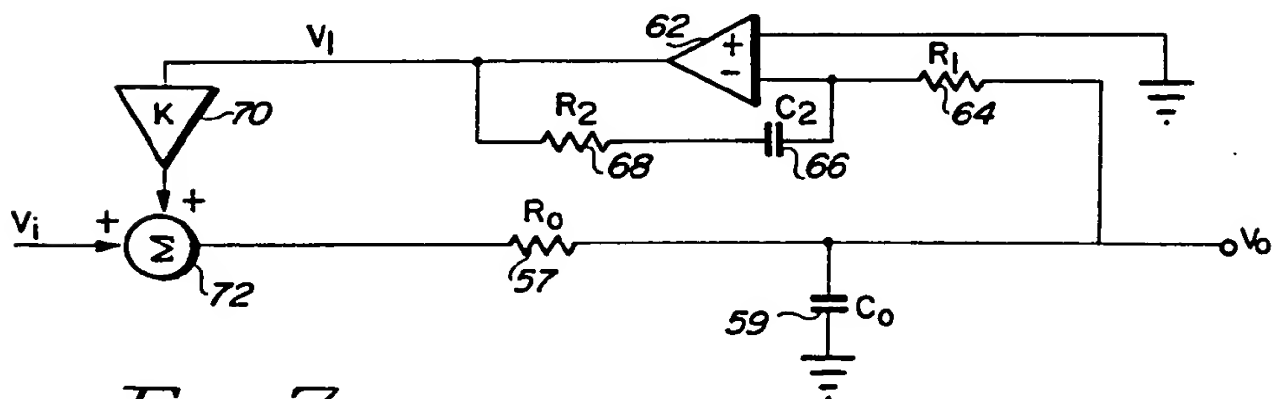


FIG. 7

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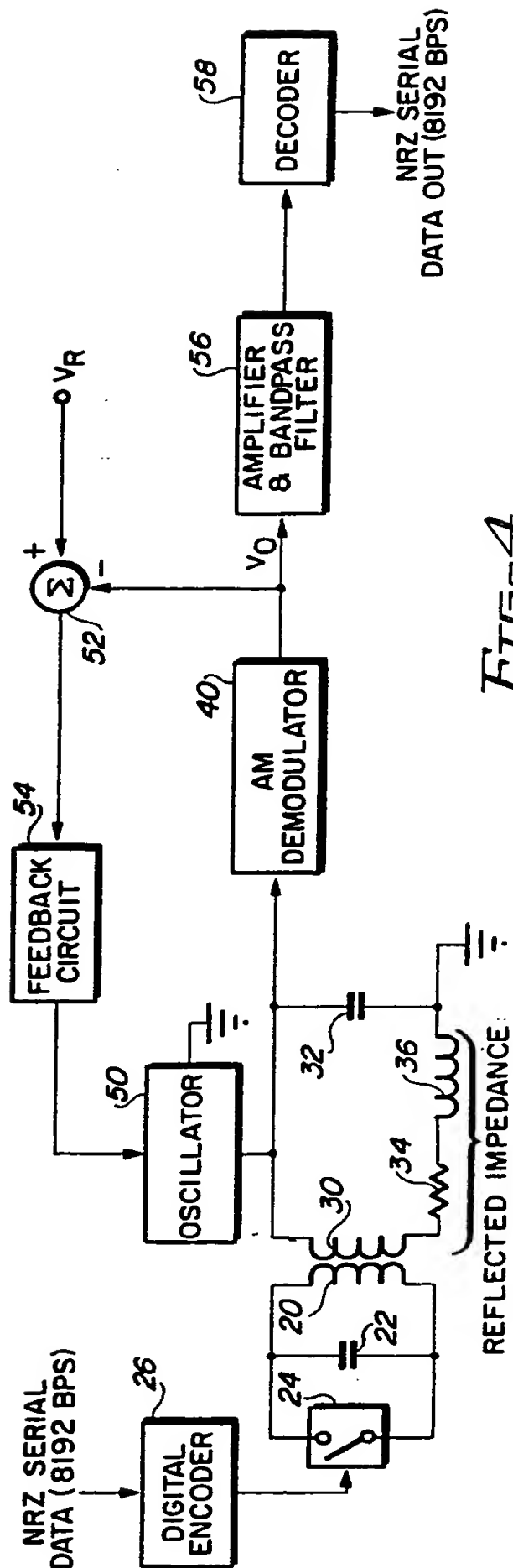


FIG 4

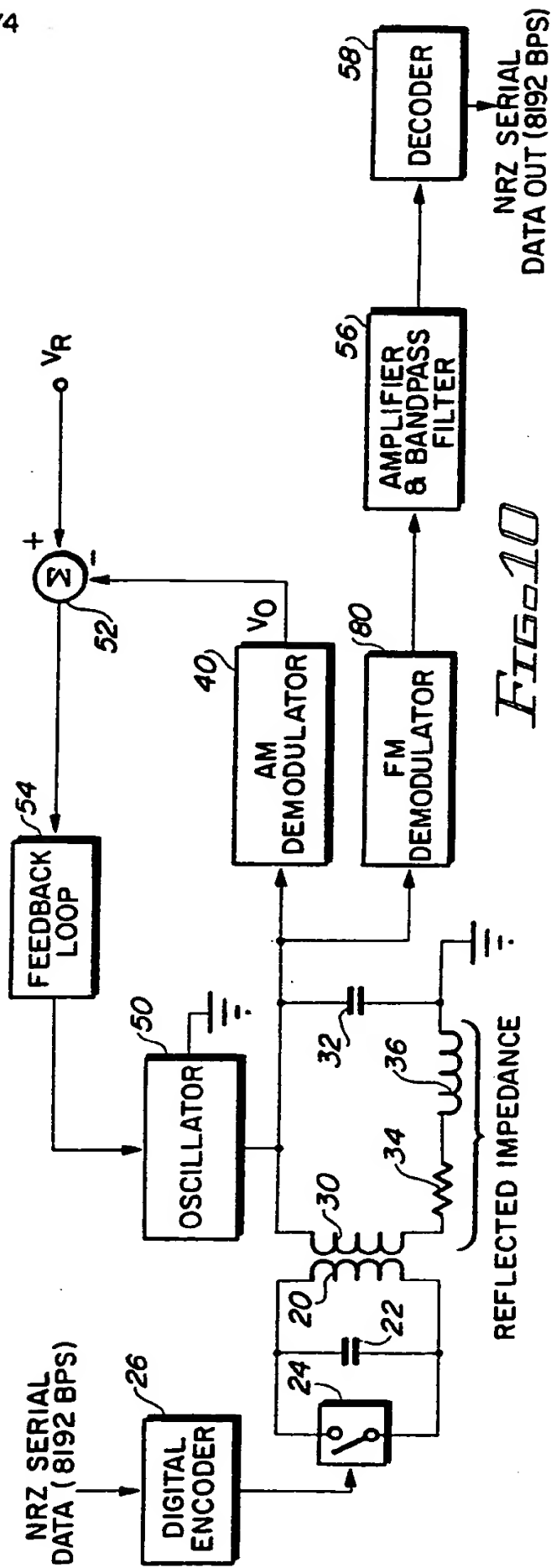
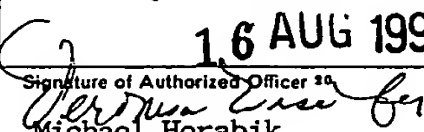


FIG 10

INTERNATIONAL SEARCH REPORT

International Application No. PCT/US90/01815

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ³		
According to International Patent Classification (IPC) or to both National Classification and IPC IPC (5) G08C 19/02, 19/04, 19/16; H03L 7/00 US Cl. 128/419PT, 903; 331/15; 340/870.180, 870.190, 870.260, 870.300, 870.420		
II. FIELDS SEARCHED		
Minimum Documentation Searched ⁴		
Classification System	Classification Symbols	
U.S.	128/696, 419PT, 903; 331/1R, 15, DIG2 340/825.540, 870.180, 870.190, 870.260, 870.390, 870.420	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched ⁵		
III. DOCUMENTS CONSIDERED TO BE RELEVANT ¹⁴		
Category ⁶	Citation of Document, ¹⁵ with indication, where appropriate, of the relevant passages ¹⁷	Relevant to Claim No. ¹⁸
Y	US, A, 2,567, 286 (HUGENHOLTZ) 11 September 1951 See figures 1 and 2.	1-20
Y	US, A, 4,083,237 (LEVESQUE) 11 April 1978 See Figures 2 and 5.	1-20
A	US, A, 4,223,679 (SCHULMAN et al) 23 September 1980 See Figures 1 and 2.	
A	US, A, 4,453,162 (MONEY et al) 05 June 1984 See figure 2	
A	US, A, 4,681,111 (SILVIAN) 21 July 1987 See figures 1, 4, 12, and 13	
A	US, A, 4,847,617 (SILVIAN) 11 July 1989 See figure 1	
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>[*] Special categories of cited documents: ¹⁵</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&" document member of the same patent family</p> </div> </div>		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search ²		Date of Mailing of this International Search Report ²
07 June 1990		16 AUG 1990
International Searching Authority ¹		Signature of Authorized Officer ²⁰
ISA/US		 Michael Horabik

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